CASR

FAA Center for Aviation Systems Reliability

Improvements in Crack Detection of Critical Rotorcraft Components

Delivery Order No IA056

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Program Team:

- **ISU**: Lisa Brasche, Mike Garton, Tim Gray

- **Bell**: Ed Hohman, Sohan Singh

- **Boeing**: Ken Dabundo, Tim De Hennis, Jim Kachelries

- **Kaman**: Paul Keary

- **Sikorsky**: Cliff Smith, John Wang

- **RITA**: Rande Vause

- **FAA Technical Monitor**: Dy Le

Objectives

- To evaluate the potential of phased array technology for typical rotorcraft applications including contact and immersion techniques

- To compare UT detection to advanced eddy current detection in those situations in which surface crack detection is relevant

- To compare advanced methods developed in this program to current techniques such as fluorescent penetrant inspection

- To develop a "lessons learned" document that provides issues in implementing phased array ultrasonic techniques for rotorcraft applications

- RD-Tech OmniScan MX portable PA instrument
  - 16/128 system
  - Acquired 1/04
  - Similar system currently in use at Bell

- "Off-the-shelf" probes limited to linear arrays

- Supplied focal law calculators address only conventional applications
  - Planar surfaces
 - Angle beam (wedge)

- Phased Array Modeling

  - Linear phased arrays

  - Contact wedge or immersion

  - Focal law tool using CAD file

  - Integrate PA into full UT measurement model, including flaw response models

- Applications

  - Sensitivity studies

  - Focal law optimization

Phased Array Model Schematic
Linear, rectangular elements

kerf

h

w

L

Phasing

Δt

(Water or wedge)

steel
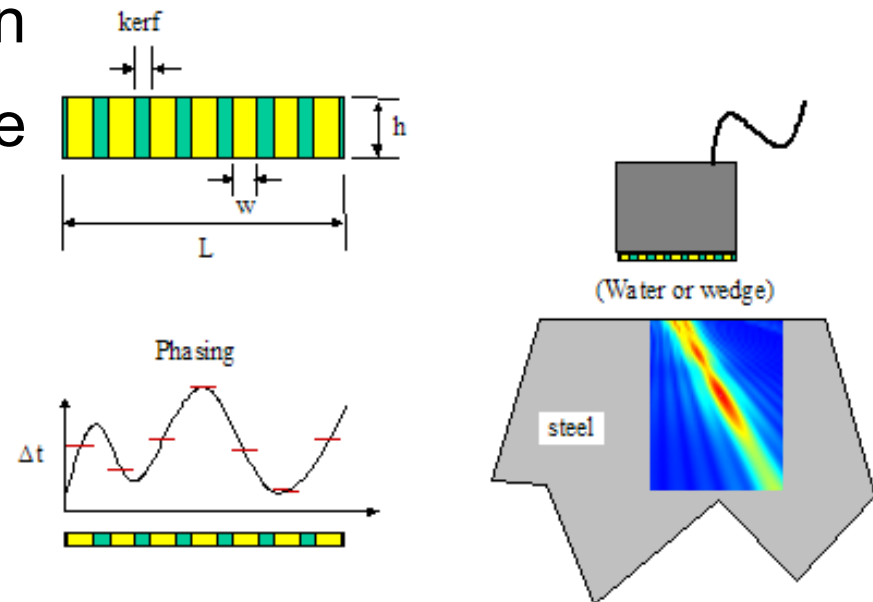
- CAD representation of component

- UTSim ray-tracing application to define delays for individual elements

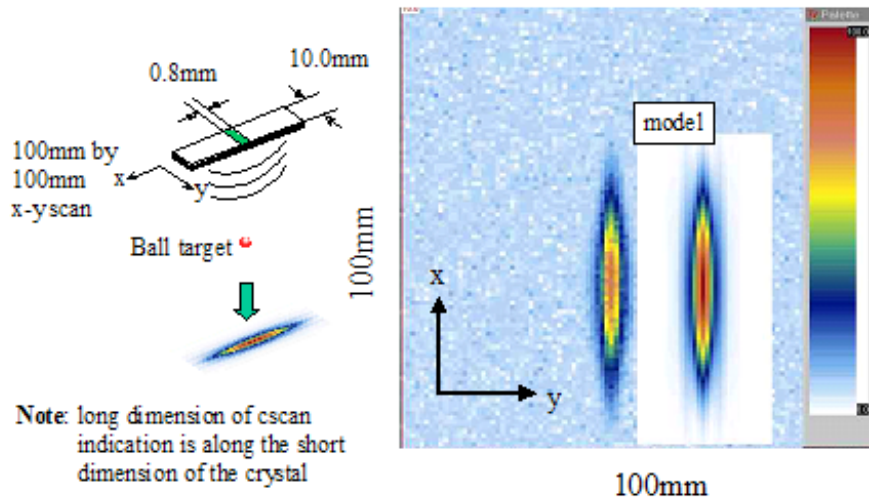- Complex shapes need "nonstandard" focal laws

Phased Array Modeling
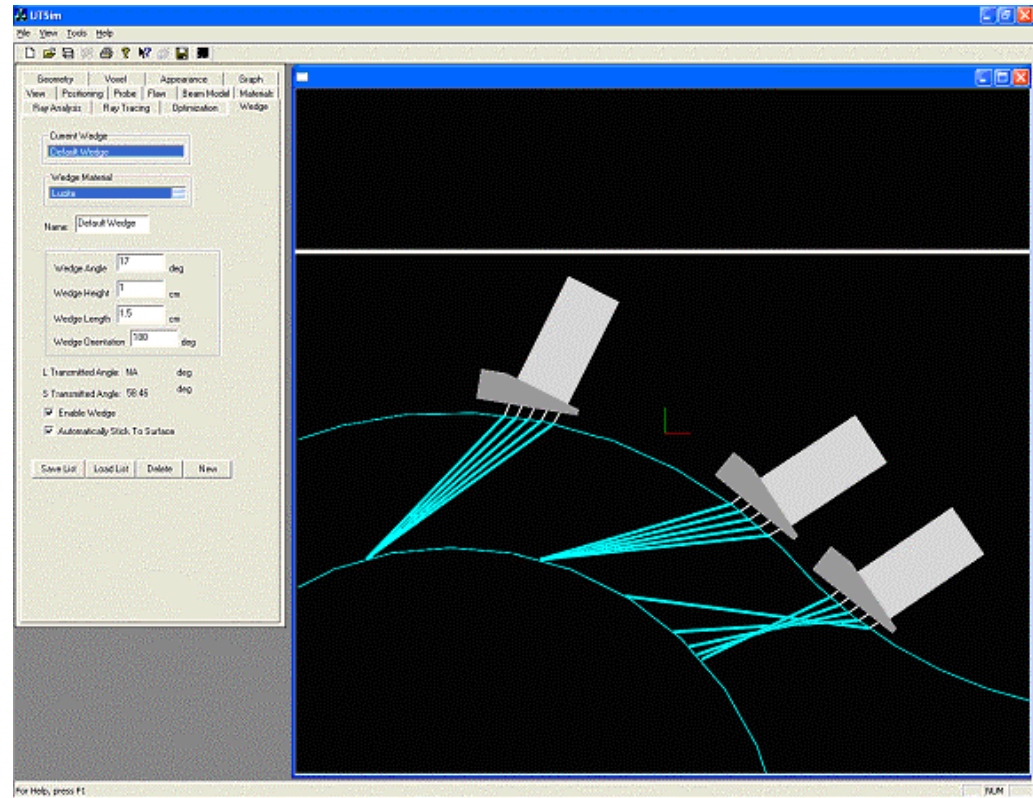
Model and Experimental C-Scan from Ball Target

Single crystal from RD-Tech linear array

0.8(x) x 10.0(y) mm element, 100mm water path

0.8mm

10.0mm

100mm by 100mm x-y scan   x

y

Ball target

Note: long dimension of cscan indication is along the short dimension of the crystal

model

100mm

x

y

100mm

Model comparison for single PA probe element

Sensitivity Plots
Definition

RF waveform
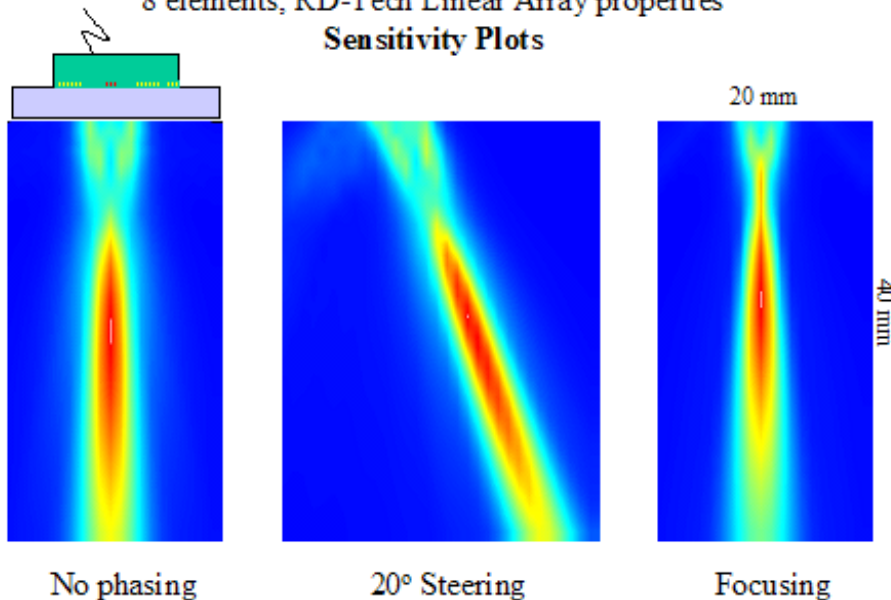
Color table

Small reflector, e.g., FBH

V_{p-p}

Steel sample

Buffer rod
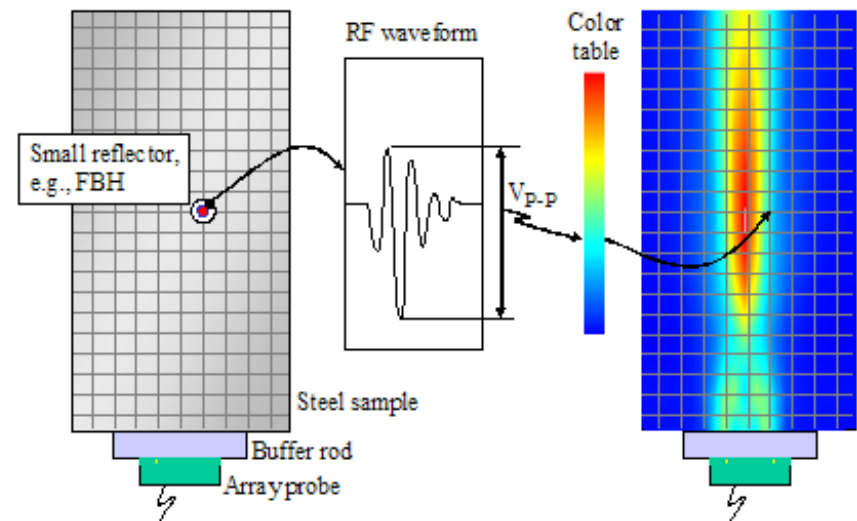
Array probe

Model: Linear Array on 0° Wedge (delay line) into Steel
8 elements, RD-Tech Linear Array properties
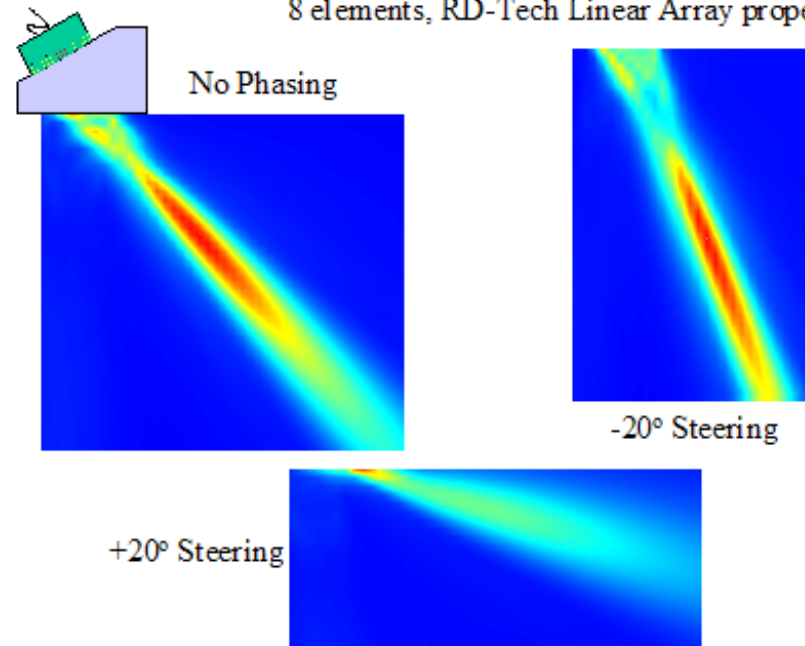**Sensitivity Plots**

20 mm

40 mm

No phasing

20° Steering

Focusing

Normal incidence wedge

45° L-wave wedge

Model: Linear Array on 45° L-wave Wedge into Steel
8 elements, RD-Tech Linear Array properties

No Phasing

-20° Steering

+20° Steering

Progress

- Subcontract in place January 2004

- Bi-weekly conference calls among technical team

- Three generic inspection concerns identified and samples provided by OEMS
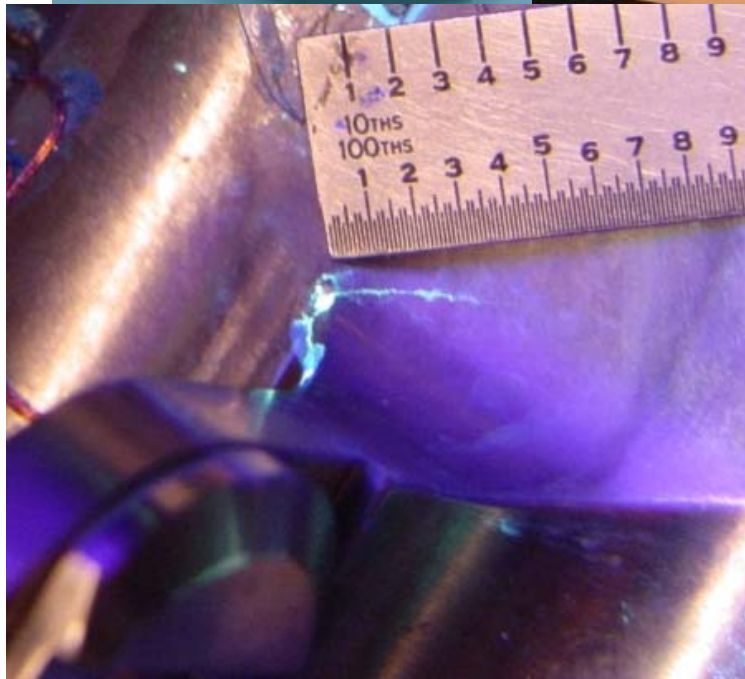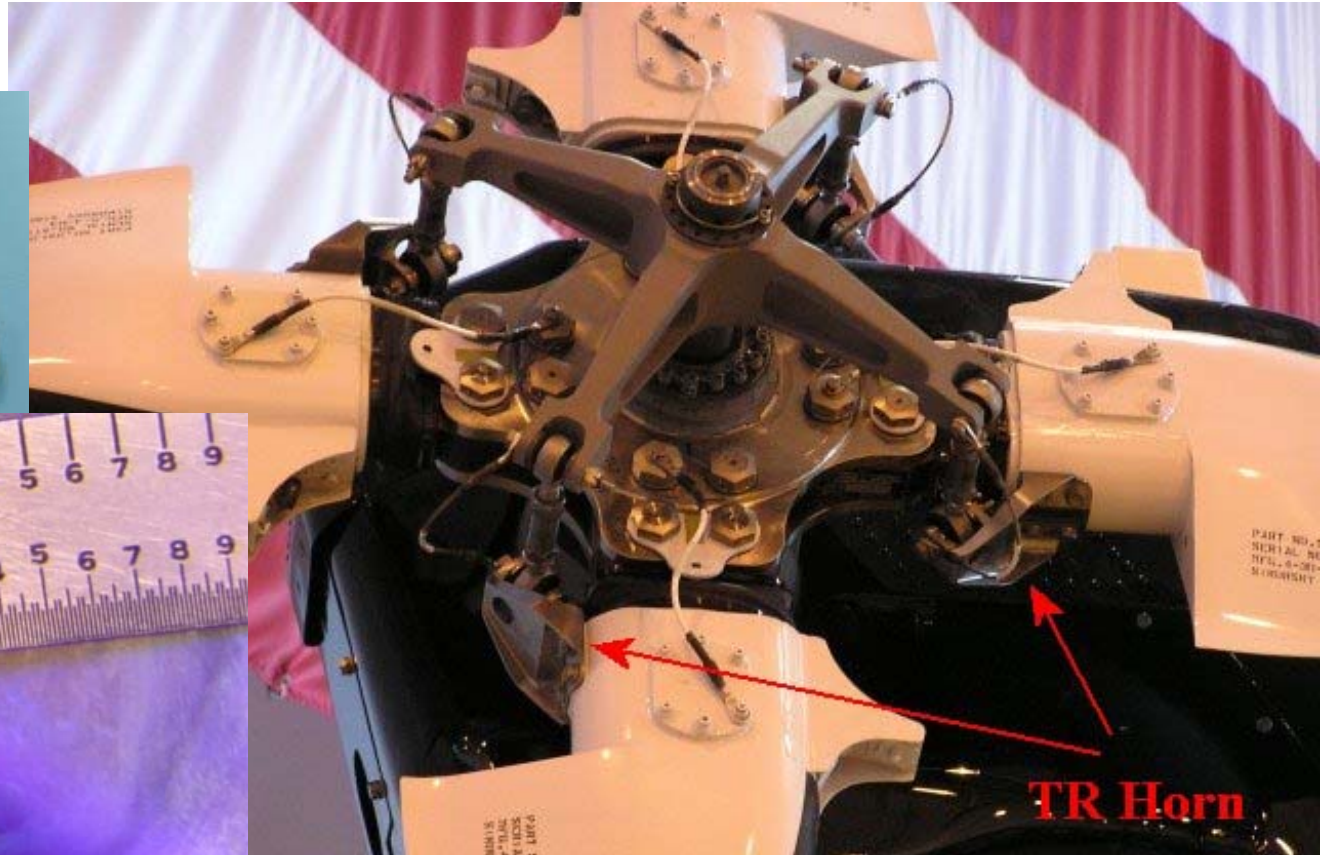
Boeing
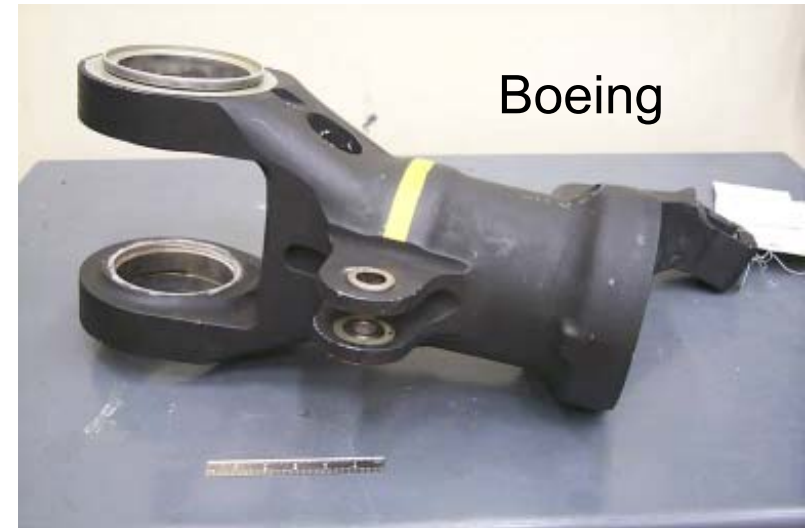
Kaman

Sikorsky

Bell

- Generic inspection features include:

    – Cracks around cylindrical IDs, such as might occur in lugs and other connection fittings

    – Defects in tubular components, particularly in electron beam weld areas

    – Cracks in flat surfaces such as mounts and other attachment fittings

- Tail rotor horn
- Cracks near base of attachment fittings

- K-Max motor mount
- Cracks in fillet region of attachment fittings

- Pitch housing

- ID cracks in lugs (EDM notches in place)

- Additional applications on swivel bearings

- Rotor shaft

- Replace current "delta" UT technique on EB weld

- Productivity issue

Progress

- ## Site visit at Sikorsky and Kaman, June '04
  - ### Attended by
    - Bell – Ed Hohman
    - Boeing – Tim DeHennis
    - Kaman – Paul Keary
    - Sikorsky – Cliff Smith, John Wang
    - RITA – Randy Vause
    - ISU – Lisa Brasche, Mike Garton, Tim Gray
  - ### Established experimental plan
  - ### Demonstrated portable PA instrument

- Establish experimental test plan and evaluation criteria for inspection optimization.

  – Cracks below flat surfaces such as mounts and other attachment fittings
    - Anticipate probes/wedges are available COTS
    - Will use (Ti) tail rotor horn (Sikorsky) and (Al) motor mount (Kaman)
    - Flaw size: 30 x 15 surface breaking crack
    - OEMs to provide information on crack orientation to assist in wedge/probe design
    - Cliff to look for precracked specimen

  – Cracks around cylindrical IDs, such as might occur in lugs and other connection fittings
    - Anticipate probes/wedges will require design optimization
    - Will use (Al) pitch housing (Boeing), (steel) bearing (Boeing), and (steel) rod-end bearing (Boeing)
    - Flaw size: 30 x 15 EDM notch (smallest notch size with other larger sizes also present)

  – Defects in tubular components, particularly in electron beam weld areas
    - Anticipate probes will require design optimization
    - Immersion application
    - Will use (steel) EB welded shaft (Bell)
    - Flaw size: 25 mil x 25 mil EDM notch; conical flaws of 11 mils (FBHeq)
    - More samples are available with conical defects

K-Max Engine Mount
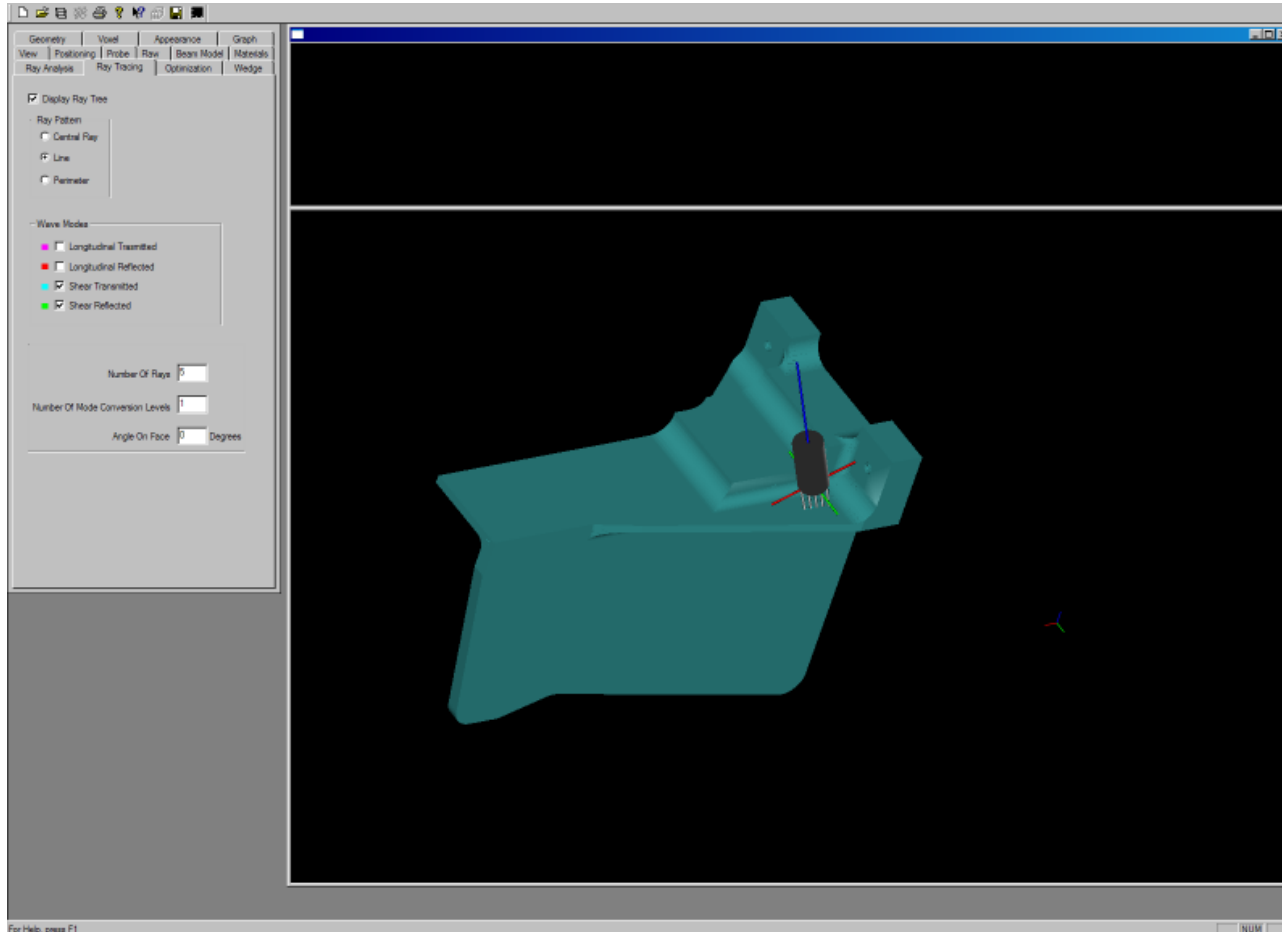
Sikorsky Tail Rotor Horn

Progress Summary
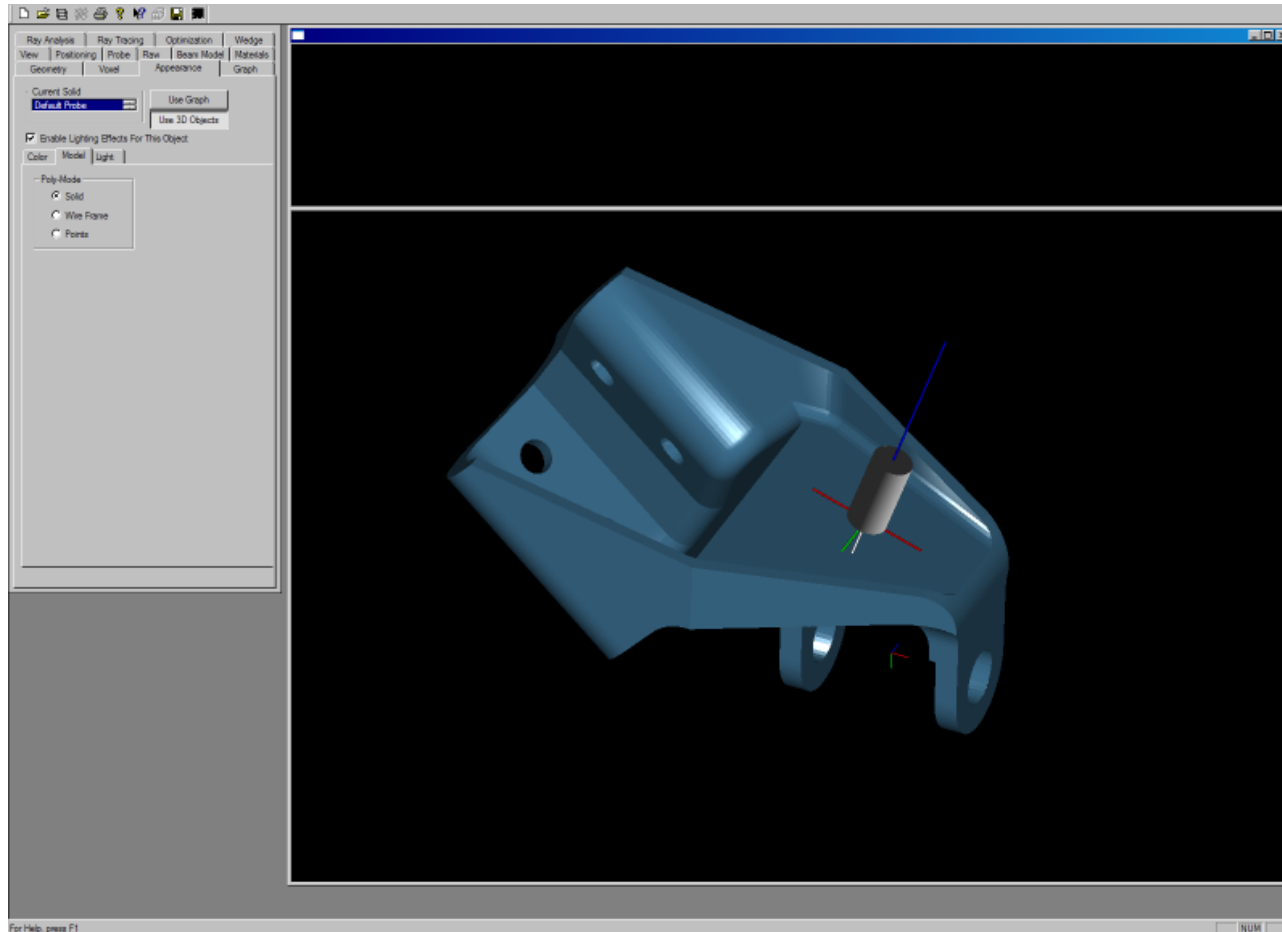
- Application examples selected from OEM input

- Phased array instrument acquired

- Site visit (Sikorsky & Kaman) led to Experimental Plan

- PA probes for 1st application ordered

- CAD files for UT modeling input, focal law definition

- Preliminary modeling/focal law computations for inspection design, 1st application
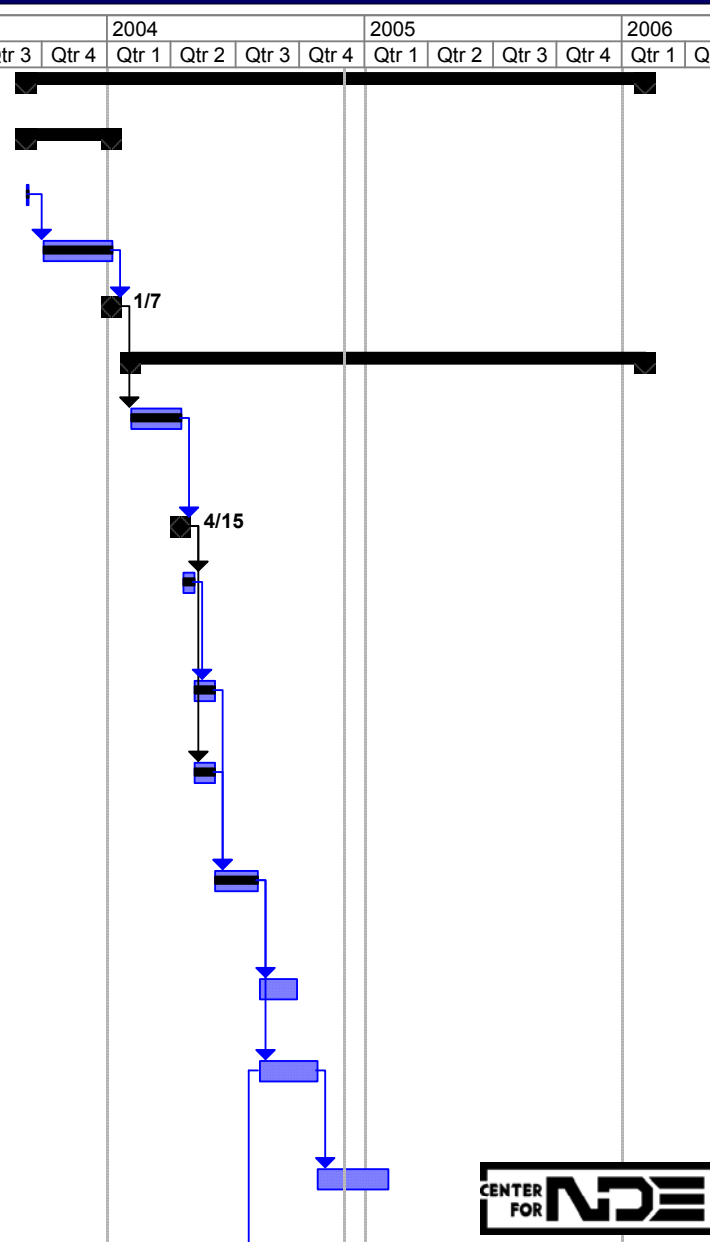
Outputs

- Jan 05 - Inspection demonstration for first component. (planned for Bell - Fort Worth)

- Feb 05 – Annual report.

- Aug 05 – Inspection demonstration for components two through four.

- Sept 05 – Field demonstration of four components. (planned for Boeing - Philadelphia)

- Nov 05 – Final meeting – (planned for Ames)

- Dec 05 – Lessons learned document incorporated into FAA draft final report.

- Jan 06 – FAA Final Report in approved format.

Project Schedule

ID		Task Name	% Complete	Duration	Start	Finish
1		**Improvements in Crack Detection of Critical Rotorcraft Components**	**26%**	**627 days?**	**Mon 9/8/03**	**Tue 1/31/06**
2	✔	**Contractual process**	**100%**	**88 days?**	**Mon 9/8/03**	**Wed 1/7/04**
3	✔	Delivery order award to ISU	100%	1 day?	Mon 9/8/03	Mon 9/8/03
4	✔	Subcontract negogiations	100%	70 days?	Wed 10/1/03	Tue 1/6/04
5	✔	Subcontract in place with RITA	100%	1 day?	Wed 1/7/04	Wed 1/7/04
6		**Technical program**	**19%**	**522 days?**	**Mon 2/2/04**	**Tue 1/31/06**
7	✔	Program planning discussion including assessment of components to be used in the study.	100%	53 days?	Mon 2/2/04	Wed 4/14/04
8	✔ 📒	Provide detailed work plan to FAA.	100%	1 day?	Thu 4/15/04	Thu 4/15/04
9	✔ 📒	Complete discussion of typical components and select one from each OEM for inspection development.	100%	11 days?	Fri 4/16/04	Fri 4/30/04
10	✔	Establish experimental test plan and evaluation criteria for inspection optimization.	100%	21 days?	Mon 5/3/04	Mon 5/31/04
11	✔	Design/acquire samples for use in inspection evaluation with fabrication to complete by the OEMs as necessary.	100%	21 days?	Mon 5/3/04	Mon 5/31/04
12	✔	Complete inspection design including probe(s) for selected components. Initiate purchase of necessary probes.	100%	44 days?	Tue 6/1/04	Fri 7/30/04
13		Complete transducer acceptance testing and characterization	0%	8 wks	Mon 8/2/04	Fri 9/24/04
14		Initiate inspection optimization using combined empirical and model based approaches for first component.	0%	12 wks	Mon 8/2/04	Fri 10/22/04
15		Complete inspection design and demonstrate to team members for first component.	0%	71 days?	Mon 10/25/04	Mon 1/31/05

Timeline columns: 2004 (Qtr 3, Qtr 4, Qtr 1, Qtr 2, Qtr 3, Qtr 4), 2005 (Qtr 1, Qtr 2, Qtr 3, Qtr 4), 2006 (Qtr 1, Q)

Milestones: 1/7, 4/15

- PA technique allows more flexible approach to inspection design for complex components
    - Variation of inspection parameters - angles, focusing, etc.
    - Tolerance variation of components

- Reduced time and effort to implement new inspection procedures
    - Initial cost is higher than conventional UT
    - Flexibility of PA focal laws allow application to variety of geometries, etc.

- Project will provide guidance to OEMs for PA application to new problems

    - Ease application of new phased array technology

- Software tool for inspection design & focal law definition will be available to OEMs (as I/U CNDE Sponsors)